GUNTER W. WYSZECKI, *Chairman*

Contributed Papers

Color, Vision, and Physiological Optics

ThD11. Two Types of Threshold Sensitivity in the Blue Region of the Spectrum. GILBERT B. LEE, *Department of Ophthalmic Surgery, University of Michigan, Ann Arbor, Michigan 48104.*—Three different luminosity curve types obtained from color normal subjects were previously described.[1] These were type-A, the largest group, resembling the classic CIE photopic curve; type-B, the deutan-looking group showing a sensitivity loss in the blue and blue-green region; and type-C, the protan or red weak group. More recent work is being reported now on two of these groups, type-A and type-B. Using a modified Stiles foveal-threshold sensitivity technique[2] one receptor mechanism at a time was altered (light-adapted) while 30 points at 10-nm intervals through the spectrum were studied. A $\frac{1}{2}°$-target flashing once/sec from a Hilger monochromator was centered in a 3.5°-field of moderately bright colored light (red, green, and blue). The subject adjusted the intensity of this stimulus test flash (0.040 sec) to his increment brightness threshold. Four type-A subjects and five type-B subjects were tested. All of the type-A group showed a loss in sensitivity to blue under blue light. None of the type-B group showed this. Their blue-adapted sensitivity threshold curves were indistinguishable in shape from their brightness-matching luminosity curves. (13 min.)

[1] G. B. Lee, J. Opt. Soc. Am. **56**, 1451 (1966).
[2] W. S. Stiles, Science **145**, 1016 (1964).

ThD12. Metamerism and Color-Rendering Indexes. I. NIMEROFF, *National Bureau of Standards, Washington, D. C. 20234.*—The color of fluorescent lamps, which emit spectral flux that consists of spectral lines and a continuum, has been customarily designated by the correlated color temperature, the temperature of a blackbody whose chromaticity most nearly matches that of the lamp. When this practice was found to give inadequate descriptions of the spectral characteristics

of these lamps and the color appearance of objects illuminated by them, a general color rendering index[1] was devised, supplemented by special color-rendering indexes. The calculation of general color-rendering index is a long procedure that involves the spectral characteristics of eight colored surfaces to sample the color gamut, two sources (the lamp and its nearest-matching blackbody), and the three CIE standard-observer functions. But, as these two sources are metameric matches (spectrally different color matches), a metameric index to describe the degree of spectral mismatch may be all that is required. In computing the metamerism index[2] only the spectral data of the two sources and the three standard-observer functions are needed. The correlation between the general color-rendering index and the metamerism index, obtained for six types of fluorescent lamps was found to be very high, 96% (10 min.)

[1] CIE Publication No. 13 (E-1.3.2) 1965 (Bureau Central de la Commission Internationale de l'Eclairage, Paris, France).
[2] I. Nimeroff and J. A. Yurow, J. Opt. Soc. Am. 55, 185 (1965).

ThD13. Matrix Model for Color Perceptability Ellipsoids. K. D. CHICKERING, *Kollmorgen Corporation Holyoke, Massachusetts 01040.*—A model relating aspects of both the Young–Helmholtz trichromatic theory and the Hering opponent response theory[1] is presented in a matrix-vector form. The model converts a vector in the system in which physical color-difference measurements are described in two stages to a vector in the system in which the eye responds to that difference. An orthogonal matrix operator is considered which transforms the perceptability ellipsoid to canonical form. The last operator results in a vector representing the conscious response of the brain as the final step in the process of color-difference perception. Influenced by the Friele model[2] and the resulting FMC equations,[3,4] this more general model contains, when suitably rewritten, the FMC equations as a special case. When applied to experimental data such as those of Brown–MacAdam,[5] the model can be used to show that the perceptability thresholds should be the positive square roots of the eigenvalues corresponding to the matrix of color-metric coefficients in the visual system. (13 min.)

[1] A. Meessen, J. Opt. Soc. Am. 58, 702 (1968).
[2] L. F. C. Friele, J. Opt. Soc. Am. 55, 1314 (1965).
[3] D. L. MacAdam, J. Opt. Soc. Am. 56, 1784 (1966).
[4] K. D. Chickering, J. Opt. Soc. Am. 57, 537 (1967).
[5] W. R. J. Brown and D. L. MacAdam, J. Opt. Soc. Am. 39, 808 (1949).

ThD14. Visibility of Colors Underwater Using Artificial Illumination. JO ANN S. KINNEY, S. M. LURIA, AND DONALD O. WEITZMAN, *Naval Submarine Medical Center, Naval Submarine Base New London, Groton, Connecticut 06340.*—The visibility of various colors underwater with artificial illumination has been measured in three different bodies of water. Subjects were SCUBA divers who observed the colors at night, using a mercury and an incandescent light source. The waters were selected to sample the continuum from very murky to clear. Colors were chosen to be representative of commercially available paints in both fluorescent and nonfluorescent types. The data are analyzed in terms of the most and least visible colors for the two lights and the various water clarities. Numerous interactions are found between color, fluorescence, light source, and water; from these results, it is possible to select the optimum combination to be used under a wide variety of conditions. These data extend the work of a previous investigation[1] in which similar experiments were performed using natural illumination conditions. (13 min.)

J. A. S. Kinney, S. M. Luria, and D. O. Weitzman, J. Opt. Soc. Am. 57, 802 (1967).

ThD15. Effect of Noise on the Modulation Transfer Function of the Visual Channel. HERBERT POLLEHN (introduced by Werner K. Weihe) AND HANS ROEHRIG, *U. S. Army Electronics Command, Night Vision Laboratory, Fort Belvoir, Virginia 22060.*—Electro-optical systems display video information to the eye of an observer. This paper is concerned with the modulation transfer function describing that part of the information which is perceived by the observer. The effect of noise on the modulation transfer function was studied by means of threshold measurements. White noise and $1/f$ noise of various levels and different cut-off frequencies were displayed on a television screen together with a sinusoidally modulated bar pattern. The signal-to-noise threshold for perception was measured as a function of the spatial frequency of the bar pattern. It was found that the signal-to-noise threshold, in addition to being strongly dependent on the bar pattern frequency, is also dependent on the rms value and the frequency distribution of the noise and on the difference between the bar pattern frequency and the mean frequency of the noise. An attempt was made to explain the results by observation of the recognition of the bar pattern in the presence of narrow bandwidth noise. (13 min.)

ThD16. Impulse Response of the Human Visual System. JOHN Z. LEVINSON, *Bell Telephone Laboratories, Inc., Murray Hill, New Jersey 07974.*—It is not enough to know the "frequency characteristic" of the visual system. (Frequency characteristics were introduced to vision by de Lange, who used sinusoidal modulation of otherwise steady light to produce flicker of independently variable frequency and amplitude.) A general stimulus may include components of several different frequencies at once, and even if these components combine linearly, the result is not computable unless the delays of the various frequencies are also known. How to measure delay without resort to microelectrodes? Previous psychophysical experiments have given ambiguous results. But a system may be described completely in another manner, namely, by its impulse (i.e., flash) response. Impulse response and frequency characteristic (including phase, or delay) are related by a Fourier transformation. It is shown that a linear system responds with greatest amplitude to a signal consisting of its impulse response reversed in time, if signals of "equal energy" are compared. Thus the problem reduces to finding that flash waveform to which the observer is most sensitive, under the restriction to waveforms for which the integrated square of the modulation amplitude is the same. (13 min.)

ThD17. Wavelength Difference Thresholds for the Detection of Square-Wave Gratings.* R. HILZ (introduced by C. R. Cavonius) AND C. R. CAVONIUS, *The Eye Research Foundation, 8710 Old Georgetown Road, Bethesda, Maryland 20014.*—Wavelength discrimination functions were measured from 480 nm to 660 nm at spatial frequencies between 2.3 cycles/degree and 18.4 cycles/degree. The wavelength difference needed to resolve gratings increases with spatial frequency in all parts of the spectrum, so that the shape of the wavelength discrimination function changes very little over a wide range of spatial frequencies. Unlike luminance difference thresholds, which often go through a minimum at low spatial frequencies, the wavelength difference threshold shows no minimum within the frequency range tested. This agrees with the results of van der Horst *et al.*[1] The effect of small suprathreshold luminance differences between adjacent grating bars was also investigated. Wavelength measured with gratings is generally improved by the introduction of these luminance differences. Also, the shape of the wavelength difference threshold (vs spatial frequency) function is changed by the introduction of luminance differences. (13 min.)

* Work supported by the Office of the Surgeon General, U. S. Army.
[1] G. J. C. van der Horst, C. M. M. de Weert, and M. Bouman, J. Opt. Soc. Am. 77, 1260 (1967).

ThD18. Cortical and Subcortical Responses to Flicker. JOSEPH F. STURR, VONNELL G. MASTRI, JOSEPH I. MARKOFF, MICHAEL S. SHANSKY, AND EHUD KAPLAN, *Department of Psychology, Syracuse University, and Syracuse Veterans Administration Hospital, Syracuse, New York 13210.*—Bipolar recordings were taken from cortex (VI) and deeper structures (OT, LGB, and radiations) in 35 anesthetized cats. A square-wave pulse train of 400 msec was presented to the right eye at three photopic luminances, at frequencies ranging from 7.5 to 100 Hz. Photic following or entrainment was defined as frequency-specific responses to the stimulus. In general, although the deeper structures followed up to the limits of the equipment (100 Hz), cortical following did not extend beyond 30–50 Hz. Above 20 Hz, entrainment in cortex and subcortex was preceded for approximately 100 msec by an initial response. The amplitude of the entrained response was systematically attenuated at higher frequencies. Below 20 Hz, entrainment appeared immediately, often with double responses to each pulse in the flicker train. The effects of levels of anesthesia are discussed. (13 min.)

ThD19. Directional and Nondirectional Auditory Feedback in Control of Eye Position. SAMUEL C. MCLAUGHLIN, MICHAEL J. DESISTO, AND MARTIN BRESLOW, *Department of Psychology, Tufts University, North Hall, Medford, Massachusetts 02155.*—The experiment started with S looking at a point of light in an otherwise darkened room, his eye position being monitored continuously by measurement of diffuse infrared reflectance from the external limbus. After 5–10 sec, the light was turned out, and S was instructed to "keep looking where the light was" for 20 sec. Whenever his eye drifted from its starting position by 1° or more, S heard an auditory signal. It has been shown [W. Smith, Psychon. Sci. 1, 233 (1964)] that eye position is more stable in the presence of such an auditory signal than in its absence—i.e., that S is able to use the auditory information as a surrogate for the missing visual feedback. In the present experiment, we evaluated stability of ocular position in the presence of each of two types of auditory feedback: a "non-directional" signal which was delivered to both ears; and a "directional" signal which was delivered to one ear or the other depending on which way the eye drifted off target. For each of three S's, the directional signal was more effective in keeping the eye "on target." (13 min.)

ThD20. Energy Level Models of Binocluar Vision. GEORGE SPERLING, *Bell Telephone Laboratories, Inc., Murray Hill, New Jersey 07974.*—The classical energy-level model consists of a marble rolling freely on a bumpy energy surface. Dips on the surface (energy-wells) represent stable states in which the marble becomes trapped. This classical model is applied to three major processes of binocular vision: accomodation (a), vergence (v), and fusion (f). Here the lateral position of the marble represents the instantaneous value of the depth plane of a (or v or f). For example, the basic surface governing vergence is bowl-shaped, this shape being determined by internal factors. The marble always rolls to the center of the bowl, representing the tendency of the eyes to verge to a neutral position in the absence of a stimulus to vergence. The external stimulus adds perturbations to the basic surface, creating new stable states. This simple model serves nicely to illustrate the path-dependence of vergence (e.g., different vergence states may occur with the same external stimulus), and it shows how extreme values of vergence can be achieved. Similar properties are proposed for a and f systems, and a complete model is presented to account for the a–v–f interactions. Although the energy models of a, v, and f are formally similar, the proposed underlying neural mechanism of fusion is fundamentally different from the others. It depends on a binocular neural field which, at any spatial x, y coordinate, permits fusion at only one depth plane and suppresses other possible fusion modes. (10 min.)

ThD21. Enhanced Sensitivity Associated with Saccades. WHITMAN A. RICHARDS, *Massachusetts Institute of Technology, Cambridge, Massachusetts 02139.*—Most previous studies which show an elevation of thresholds associated with the saccade have used test-flashes presented against a background. No saccadic effect was found, however, in at least one study using no background.[1] These differences imply that the background level may be an independent variable which can alter the effects of saccades on thresholds. To examine this variable, foveal thresholds for a test-flash which followed a saccade by 40 msec were determined at 13 wavelengths for two real-light backgrounds, 471 and 645 nm. In each case, the maximum suppression associated with the saccade occurred for wavelengths in the neighborhood of the background wavelength. This suggests that the effect of the saccade is to raise the noise of the real-light background rather than to attenuate the incoming test-flash signal. A second study of the importance of background activity compared the effects of a real-light background vs its after-image. Contrary to what is found for a real-light background, the flash could be detected much more readily against the after-image if a saccade had been made. This observation of "saccadic enhancement" is as if the effect of the eye movement is to wipe-out that part of the background noise associated with the after-image, thus improving signal detectability. These differences between the real-light and after-image backgrounds may be interpreted as a release of lateral inhibition following the saccade. (13 min.)

[1] J. Krauskopf, V. Graf, and K. Gaarder, Am. J. Psychol. 71, 73 (1966).

ThD22. Computer Analysis of the Electroretinograms. STANLEY BUCKSER, *Department of Biology, East Carolina University, Greenville, North Carolina 27834.*—A simple model was assumed regarding the electroretinogram (ERG) as the summation of potentials produced by three different processes initiated by a light flash stimulus. The first process corresponds to the initial negative potential, the *a*-wave. Rising from the *a*-wave with positive polarity is the rise portion of the *b*-wave, the second process. The *b*-wave reaches a maximum and falls off in the decline portion of the *b*-wave, represented by the third process. Each of these processes is assumed to have the form: $f(t)=C\cdot\{1-\exp[-k(t-J)]\}$. These functions can be derived from physiological phenomena, e.g., ion diffusion across a membrane with the observed potential being proportional to the difference in concentration between intracellular space and the surrounding medium. A series of ERG's was obtained from a curarized dark-adapted albino rat in response to a constant light stimulus during various stages of anoxia. This fractionates the *a*-wave as the ERG *b*-wave decreases with increasing anoxia, and finally disappears, leaving only the *a*-wave. This is reversible when oxygen is supplied. Five curves of this series at different stages of anoxia were digitized and put in a form suitable for processing by the IBM 7094 computer. Programs were written which systematically vary the parameters of the model in such a way as to reduce the sum of squares of differences between the model and the experimental data. Final parameters are obtained when the algorithm can no longer reduce the sum of squares. The fit between the experimental data and the summated functions of the model for the various stages of anoxia is examined and a view of each process, uncomplicated by the others occurring in the same ERG, is obtained. A discussion of the basic parameters and others derived from the model and their change with anoxia is given. (13 min.)